DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Waves, Bubbles, Noise and Underwater Communications

Grant B. Deane
Marine Physical Laboratory
Scripps Institution of Oceanography
UCSD, La Jolla, CA 92093-0238
phone: (858) 534-0536 fax: (858) 534-7641 email: gdeane@ucsd.edu

Grant Number: N00014-04-1-0728

LONG-TERM GOALS

The long-term goal is to develop physical models for the role of surface waves and bubbles on the performance of high-frequency, coherent underwater communications systems. These models will be used as the basis of improved signal processing algorithms for underwater acoustic modems, and to develop predictive algorithms for the performance of modems operated beneath wind and waves.

Modem performance is impacted by signal-to-noise ratio at the receiver and reverberation levels determined by scattering from the sea surface and seafloor. Waves impact both of these processes by radiating noise when they break and by focusing and scattering surface-reflected sound. They also influence surface reverberation by injecting micro-bubbles into the upper ocean boundary layer that scatter and attenuate sound.

Because of these wave-drive processes, one long-term goal is to measure, model and exploit the surface-focused acoustic arrivals occurring on short length scales beneath sea swell and study their impact on underwater communications systems in the littoral and near-shore regions. The final long-term goal of this grant, to understand the physical mechanisms responsible for the Knudsen spectrum for wind-driven underwater ambient noise, has been achieved.

OBJECTIVES

Work over the past 12 months has focused on 2 main objectives, which have been to: (1) analyze and model the Surface Processes and Communications Experiment (SPACE08) data collected as part of the field expedition at the WHOI Coastal Observatory during fall of 2008, and (2) incorporate the effects of atteunation and scattering of bubbles into a propagation model that also accounts for surface scattering in the presence of surface gravity waves.

APPROACH

The underlying approach consists of field and laboratory experiments, combined with numerical and analytical models of the physical processes under study (the production of bubbles and noise by breaking waves and the focussing and scattering of sound from surface waves).

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2010		**00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE	
Waves, Bubbles, Noise and Underwater Communications	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, San Diego,Scripps Institution of Oceanography,Marine Physical Laboratory,La Jolla,CA,92093-0238**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Surface scattering by gravity waves. This work has been done in collaboration with Dr. Chris Tindle at the University of Auckland, New Zealand, and Dr. James Preisig at the Woods Hole Oceanographic Institution. Work with Dr. Tindle has centerd on the creation of a numercial code to compute the acoustic field in shallow water with surface waves and bubbles (the wavefronts propagation model). The ultimate objective of this effort is to incorporate the acoustic model into a shallow-water channel performance simulator for high-frequency, coherent communications. A second-year graduate student at SIO (Sean Walstead) will be working on this problem over the next 24 months.

In addition to the development of a shallow-water propagation code, part of the approach is to develop a model relating the statistics of surface-reflected arrivals focused by gravity waves to the statistics of the waves themselves. Because the growth of surface waves for a specified fetch, wind speed and water depth is now relatively well-understood, it should be possible to predict the statistics of wave-focused arrivals and their impact of underwater acoustic communications systems by specifying these environmental parameters.

Near-surface bubble effects on sound scattering. The approach here has been to undertake field and laboratory experiments to examine bubble production by breaking waves and to incorporate the effects of bubble scattering and attenuation into the wavefronts propagation model. Extensive field data from video cameras pointed at the sea surface has been collected from the Air-Sea Interaction Tower at the Martha's Vineyard Coastal Observatory and laboratory tank experiments have been undertaken to study micro-bubble production by breaking waves. The environmental data sets of wave breaking and the wavefronts propagation model will be used to test our understanding of the role of micro-bubbles on the forward-scatter of sound from the sea surface in the presence of gravity waves. An extensive data set of propagation signals is available from the SPACE08 communications experiment, which encompassed a wide range of wind speeds and sea states. This data set will be compared with model predictions from the wavefronts propagation code and environmental inputs (wind speed, wind direction and fetch).

Wave noise modeling. As with the other components of work, the approach to wave noise modeling has been to combine laboratory and field data with analytical and numerical models to gain a basic understanding of the physical origin of the noise and develop a predictive capability of noise based on wind speed and wave breaking. The results of this work are detailed in the FY09 report to ONR.

WORK COMPLETED

The Surface Processes and Acosutic Communications Experiment (SPACE08). The SPACE08 experiment was conducted during the fall of 08 at the WHOI Martha's Vineyard Coastal Observatory. Two key data sets from this experiment and an earlier communications experiment at the same site in 2002 have been analyzed. These are the forward scatter of surface-reflected acoustic signals from surface gravity waves and video footage of whitecap coverage over a range of wind speeds and directions.

The acoustic transmission data was taken along a 68 m propagation path in 15 m deep water at workhorse communications frequencies. The transmission data is supplemented with measurements of the sea surface elevation above the sea floor using a multi-frequency acoustic Doppler sonar deployed by Dr. Andone Lavery from WHOI at the mid-point of the propagation path. The sonar data provided a time-series of sea surface height simultaneously with the acoustic transmission data, allowing a

reconciliation between observed surface scattered arrivals and the arrival structure predicted by the Wavefronts model.

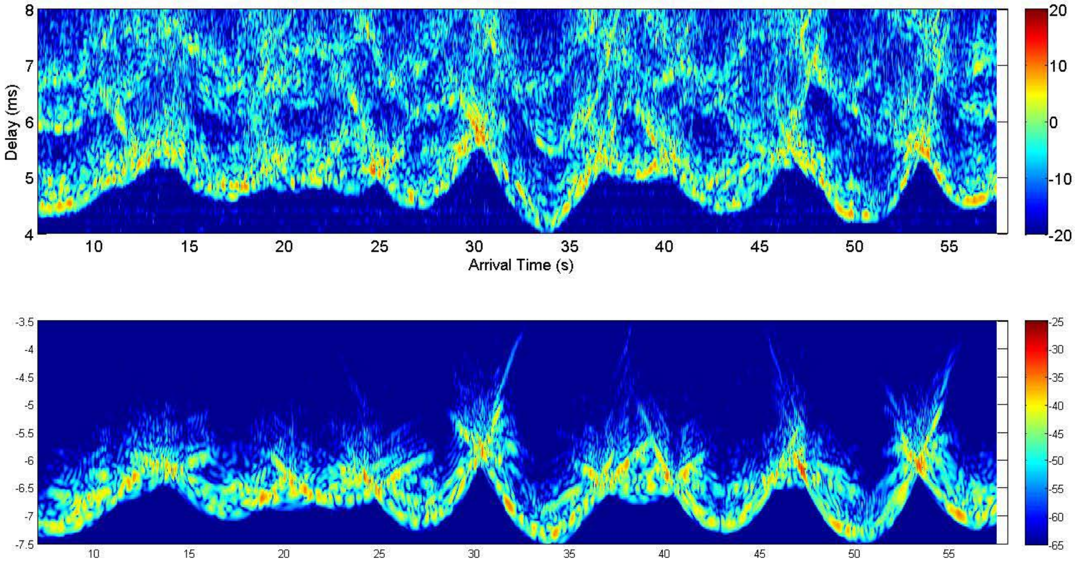

Figure 1. An example of measured and modeled surface-scattered data from the SPACE08 experiment. The top plate shows the amplitude of arrivals as a function of propagation delay stacked vertically. This data was collected by Jim Preisig. The horizontal axis is transmission time in seconds. The direct and bottom-reflected arrivals have been removed from the figure so that the first band of arrivals correspond to energy reflected from the sea surface. Later arrivals correspond to surface-bottom and bottom-surface reflections. The second plate shows the surface-reflected arrival structure calculated using the surface elevation times series provided by Andone Lavery. [Note that the delay axis is offset by 11.5 ms and the amplitude color scale is offset by 45 dB between the two plots. The span of the axes is the same].

Figure 1 shows a reconciliation between the measured reverberation and reverberation modeled using the measured surface elevation time series (only the first surface reflection has been modeled). The model calculates only the first surface reflection, and so does not include the energy from multiple boundary interactions seen in the data after approximately 6 ms. The surface wave elevation profile used to model the scattered acoustic energy was calculated from the sonar time series using a pseudo-harmonic analysis.

The relatively good agreement between the model and data shows that the deterministic features of the arrival structure can be reproduced. The variations in arrival time of the surface-reflected sound are in good agreement with the observations. The variations in arrival amplitude also show some agreement, although more variance between the model and data can be seen.

Analysis of SPACE02 Video Imagery. In addition to focusing surface reflections, gravity waves also break and entrain clouds of bubbles during periods of moderate to high wind speed. The episodic injection of high void fraction bubble plumes feeds the background layer of microbubbles responsible for scattering and absorbing the forward transmission of sound through the upper meter or so of the

upper ocean boundary layer. This bubble layer acts a screen between underwater acoustic communication systems and the ocean surface. One way of characterizing the injection of these bubbles is to photograph their surface expression, or white caps.

Video imagery of the breaking wave field was taken during both SPACE02 and SPACE08 deployments. Approximately 1 million surface images have been analyzed using automated computer processing algorithms for white cap coverage as a function of wind speed and direction.

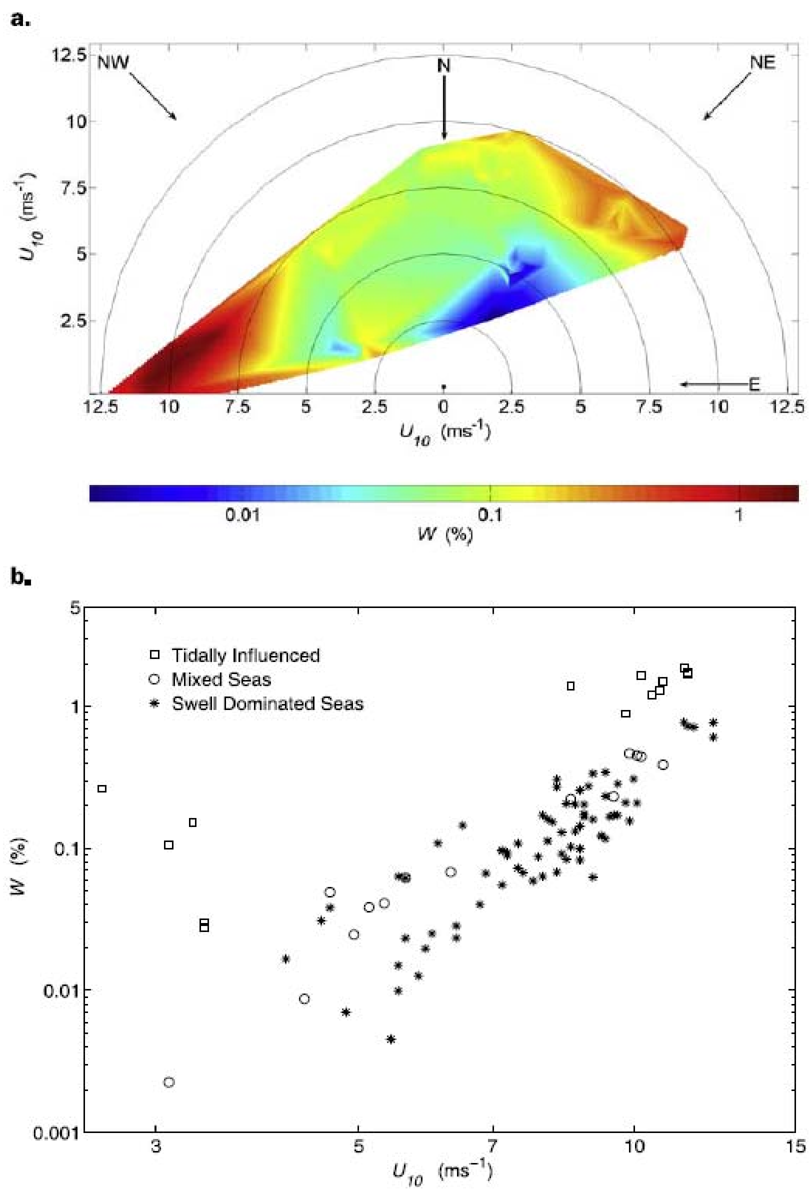

Figure 2. Analysis of video imagery to recover whitecap coverage as a function of wind speed and direction during the SPACE02 deployment. A. The color bar represents percentage of the ocean surface covered by white caps as a function of wind speed and direction. B. White cap coverage as a funciton of wind speed only. This data has been organized into percentage coverage during swell dominated seas, mixed seas, and tidally influenced periods.

A summary of this analysis for the SPACE02 data is shown in figure 2. As we expect from previous studies, white cap coverage shows a power law dependence on wind speed. This analysis also shows a sensitivity of white cap coverage to sea state (mixed versus swell-dominated seas) and a significant sensitivity to tidal flow.

Acoustic propagation in the presence of bubbles: Experiments and modeling. The wavefronts model, developed in collaboration with Dr. Chris Tindle at the University of Auckland, has been modified to incorporate the effects of bubble attenuation and range-dependent sound speed. Scale model tank experiments have also been conducted to measure the attenuation of sound beneath laboratory plunging waves. The data from these experiments has yet to be reconciled with the modified wavefronts propagation code.

RESULTS

Determinisitic modelling of surface scattering from gravity waves. The measurement and modeling exercise demonstrated that it is possible in the open ocean to deterministically reconcile observed wave focusing with model predicitons. It was not obvious before the fact that this could be accomplished, but having done so we can now begin the task of relating the amplitude statistics of surface reflected arrivals to surface conditions. This will enable us to 1) develop a predictive capacity for signal propagation conditions for a specified sea state and 2) facilitate Jim Preisigs development of improved signal processing algorithms for underwater communication systems receivers.

The analysis of white cap statistics. The white cap statistic analysis demonstrates that white cap coverage is sensitive to not only wind speed, but also sea state and other environmental factors such as sheared tidal flows. This result has a number of important implications. For example, the Knudsen curves for undersea shallow water ambient noise are typically characterized in terms of wind speed only. However, the sensitivity of wave breaking to sheared tidal flow indicates that wave breaking noise cannot be accurately predicted from wind speed alone. The implication is that we can significantly improve the prediction of ambient noise levels by encorporating other environmental factors, such as bathymetry and tidal flows, in addition to wind speed into wave breaking models.

IMPACT/APPLICATIONS

The accurate reconciliation of wave measurements with deterministic measurements of forward-scattered sound from the ocean surface has important implications for both modeling and understanding the performance of underwater acoustic communications systems. Once the relationship between wave statistics and forward-scattered, wave-focused arrivals is understood, it will be possible to predict the performance of underwater network scenarios given a set of measured environmental parameters. Accurate predictions of signal to noise ratio and screening of the ocean surface by clouds of wave-induced bubbles are also important for modeling underwater communications performance.

RELATED PROJECTS

“Underwater Acoustic Propagation and Communications: A coupled research program”, funded under the Multidisciplinary University Research Initiative (MURI) by ONR.

PUBLICATIONS

Czerski, H. and Deane, G.B. “The effect of coupling on bubble fragmentation acoustics,” J. Acoust. Soc. Am., 2010 [IN PRESS].